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Mine Emergency Escape and Response Technology

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ABSTRACT: This paper will present current investigations into the use of vision enhancement and scanning technology that can enable the navigation and manoeuvrability of a self-escape vehicle through dense dust and smoke. This paper will also present research into instrumentation and communication for obtaining information following an emergency event.

INTRODUCTION

In the aftermath of recent major mine disasters there has been much debate around tactical and emergency response and preparedness. This falls into two broad categories: (1) self-escape, and (2) rescue and recovery. In these situations, the primary objective is always to facilitate and enable the self-escape of mine personnel to safety in the first instance. However, this is often not possible and crucial time-critical decisions are required of the emergency services. Common shortfalls in emergency response includes the failure to capture and/or process key information, lack of mine environmental information (current and/or previous information leading up to such an event), limited knowledge of workforce status and location, and consequently increased uncertainty in determining the risk for the response and recovery team tasked with re-entering the mine.

Simtars are currently engaged in research into developing and testing optical and scanning technology that can be retrofitted to a mine vehicle to provide navigation assistance and thus enable escape during emergency events. One of the key issues is that loss of visual sight and location awareness, particularly due to the presence of smoke and dust, can significantly impair or even completely prevent the ability for a mine worker to self-navigate the vehicle out of a mine even in low concentrations (Kissell and Litton 1992). Therefore, technology is needed to aid the driver's own ability to locate their relative position, direction of travel and avoid impacting obstacles and/or the mine walls.

Previous tests were carried out at Simtars in 2013 using the SICK laser scanning (LIDAR-based) technology. A comprehensive set of trials were conducted to test the SICK laser scanners' performance under outdoor conditions, and in the presence of both dust and smoke. Tests were also carried out using a polycarbonate, or 'Lexan', clear screen with the view that this would be required in an Ex-certified end product. The main results demonstrated the severe limitations that both smoke and dust cause. In most cases the absolute maximum range achieved under worst-case conditions was 5 m, and in some instances the target obstacle was only detected at a maximum of 2 m distance. Due to the nature and conditions of these previous trials, the smoke tests obtained were qualitative due to the environment used, and lack of equipment available to measure the smoke quantity at the time. However, different types of smoke were trialled: 'Black smoke' through burning a mixture of fuels, and other substances to generate a think soot-rich smoke, and 'white smoke' through wood and other materials. As expected, the black smoke had a significantly increased adverse effect on the measurements opposed to white smoke. Whist the qualitative data was limited these trials provided a useful reference indication of performance for future work. Testing was also carried out using coal dust in 'worst case' concentrations of ~60 g/m^3. The effect of the dust on the laser scanning equipment was more severe than the smoke test results.

During the recent testing programme, Simtars have been conducting a series of tests in different environments ranging from small-scale through to large scale live fire tests. Simtars have recently constructed a purpose built Dust and Smoke Test Chamber with instrumentation to quantify the

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measurements. All testing, including the results presented in this paper were carried out using this test facility, except for the live fire tests that were carried out at Queensland Fire and Emergency Services (QFES) Live Fire Training Centre.

The vision enhancement technologies currently being trialled by Simtars are Short Wave Infrared (SWIR) and Long Wave Infrared (LWIR). SWIR technology, typically used across the 900 nm (nanometers) to 1700 nm wavelengths, uses Indium Gallium Arsenide (InGaAs) sensors for detection. It is beyond the visible spectrum and is often used at 1550 nm, which is eye-safe.

LWIR, or more commonly referred to as thermal-infrared, technology is typically used in the 8 - 12 µm wavelength range. It is a highly established technology for heat measurement among many other thermographic applications. In theory, the longer wavelength will have better penetration through small particle clouds, however the images are completely restricted to heat sources and it is likely that the images will become quickly saturated in smoke and dust. Figure 1 shows the visible, SWIR and LWIR spectrums.

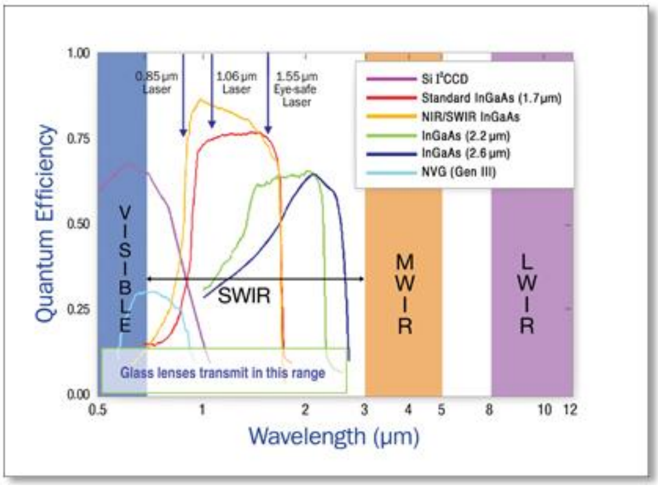

Figure 1: Diagram showing the visible, SWIR and LWIR spectrums (from UTC Aerospace Systems 2016)

TEST EQUIPMENT

Simtars has built a dust and smoke test chamber at its headquarters in Redbank. It consists of three 40' length shipping containers joined end to end, covered externally with 100 mm thick insulation panelling. Figure 2 shows the exterior of the chamber and the exhaust fan.

Figure 2: Simtars Dust and Smoke Test Chamber, the rear of the test chamber is shown with the exhaust fan

The exhaust fan at the rear of the chamber has a diameter of 630 mm. It has a variable speed controller. This allows the fan to be turned on such that it applies only a small pressure differential to the test chamber while a test is being conducted. This prevents dust and smoke from entering the control room. When a test is finished, the fan speed can be increased to quickly evacuate the test chamber of dust and smoke.

Internally the containers have been divided into three rooms: a monitoring and control room of approximately 12 m in length, a test room approximately 12 m in length and an exhausting chamber of approximately 12 m in length. The control room allows the operators to remotely fill the test room with smoke and monitor the data being recorded, such as the opacity of the atmosphere.

A Sick DustHunter is used to monitor the opacity of the test room. This unit was chosen as in order to provide continuous reliable results it uses an air purging system to prevent any clogging of dust around the sensors. Barrel fans are placed on the floor of the test room to mix the dust/smoke atmosphere and assist in achieving a homogenous mixture.

As shown in Figure 3, a "target" frame is mounted on a pulley system so that its position can be moved, from control room, during a test. The frame is designed to accommodate difference payloads such as light targets or objects. A wire line encoder has also been installed to accurately record the distance, or longitudinal position, of the frame during testing. The LED light beacons, as shown in Figure 3, can also be installed on the target frame. The red, blue, green and amber colours are used for the different wavelengths across the visible spectrum. They also give a visual reference point from the control room as to how opaque is the atmosphere in the test room. Testing conducted by NIOSH suggests that in underground mine environments green light is more easily detected through smoke in emergency conditions due to the typical low-light environment, presence of dust, and the typically high average age of the workforce (Sammarco 2012). As part of this study Simtars are also evaluating the visibility of the beacons in both smoke and dust conditions.

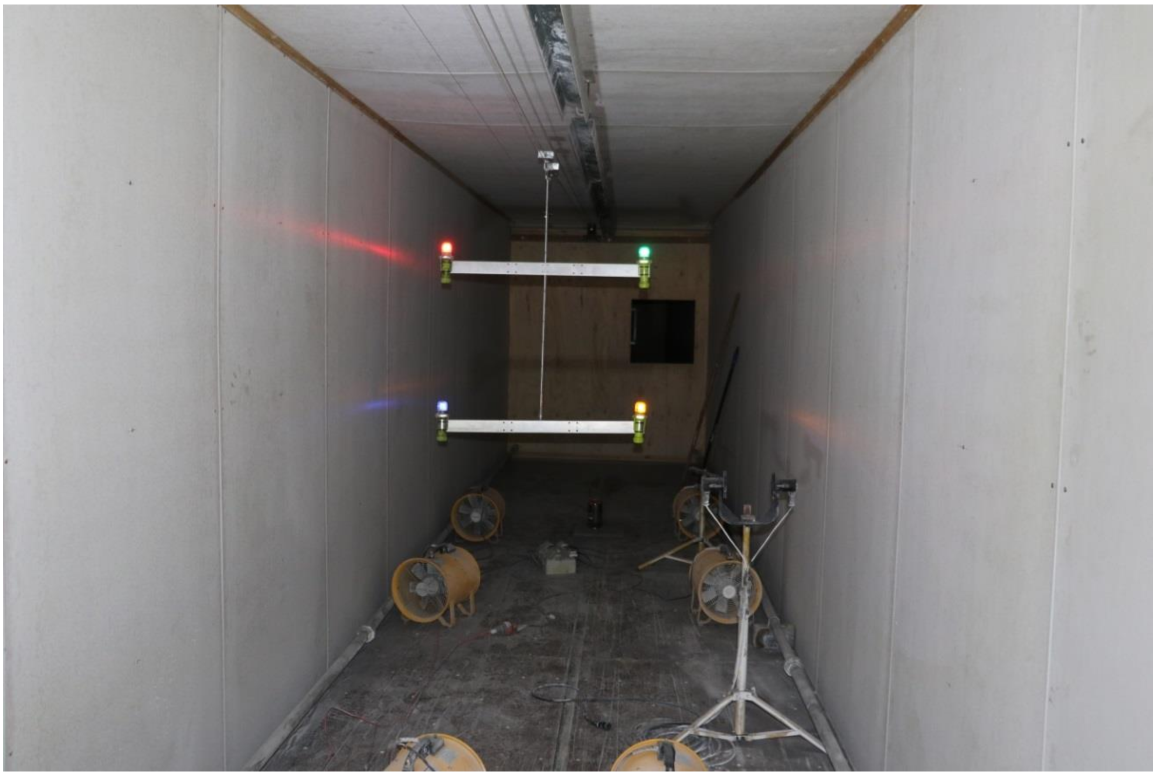

Figure 3: The test room inside the Simtars Dust and Smoke Test Chamber, note that the moveable target frame with the LED beacons, also visible are fans for circulating dust and the opacity meter

In addition to the LED light beacons in the visible spectrum, LED SWIR beacons are used to test the ability of the SWIR camera to see through dust and smoke. They emit at either 1050 nm or 1550 nm. They are shown in Figure 4. The LED SWIR beacons were specifically made for this study by the manufacturer.

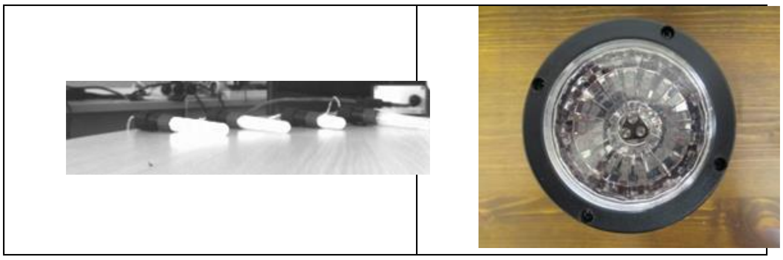

Figure 4 : LED SWIR 1050 nm and 1550 nm beacons and a SWIR Lambertian Reflector

Similar to the above application described for the SWIR beacons, Simtars have also investigated the use of thermal IR beacons for detection through the presence of dust. Figure 5 shows the thermal IR beacon that will be used. It emits in the 8-12 micron spectrum.

Figure 5: MS-OMR II (8-12 model) Beacon (from Thermal Beacon 2003)

Simtars is currently evaluating a SWIRcamera and two thermal infra-red cameras. The images from these cameras are compared to footage taken with a standard CCTV camera. Table 1 lists the model details and image type of the cameras that have been tested by Simtars to date. Other technologies are also being considered for testing in the Simtars Dust and Smoke Test Chamber, for example Lidar systems, Radar, and other wireless navigation systems.

Table 1: Cameras used in low visibility tests conducted by Simtars to date

Camera Model	Image Type
Photonics Science SWIR	Short wave infra-red (SWIR)
FLIR PathFindIR	Long wave infra-red (LWIR)
Nautitech Thermal Infra-Red	Long wave infra-red (LWIR)
Sony CCD Monochrome	Visible CCD

LIVE FIRE RESULTS

The Queensland Fire and Emergency Service (QFES) facility on Whyte Island has the capability of conducting live fire tests. In conjunction with QFES, and University of Queensland (UQ) Simtars conducted a series of tests at this facility using a standard CCTV camera, SWIR camera, and two thermal LWIR cameras. The test building that was used consisted of two levels, with multiple rooms on each level. A fire was initiated in an adjacent room (burn room) and the smoke from this fire was allowed to build and pass into a second room (smoke testing room), in which light beacons and an opacity meter were set up. In a third room (camera room), cameras were positioned such that the light beacons were able to be monitored. Figure 6 shows the layout of the rooms used. The distance of the smoke testing room is 10 m.

The fuel used in all fire experiments was kerosene. The density (and hence soot-content) was controlled by limiting the ventilation into the burn area. The smoke was allowed to build through the stages of the fire into the smoke testing room. The smoke opacity meter was used to record the smoke levels in real-time throughout the testing. LED beacons were also used to record the visual visibility by the human eye throughout the testing. Figure 7 shows photos of the LEDs in the smoke test room during different progressing stages of a fire test.

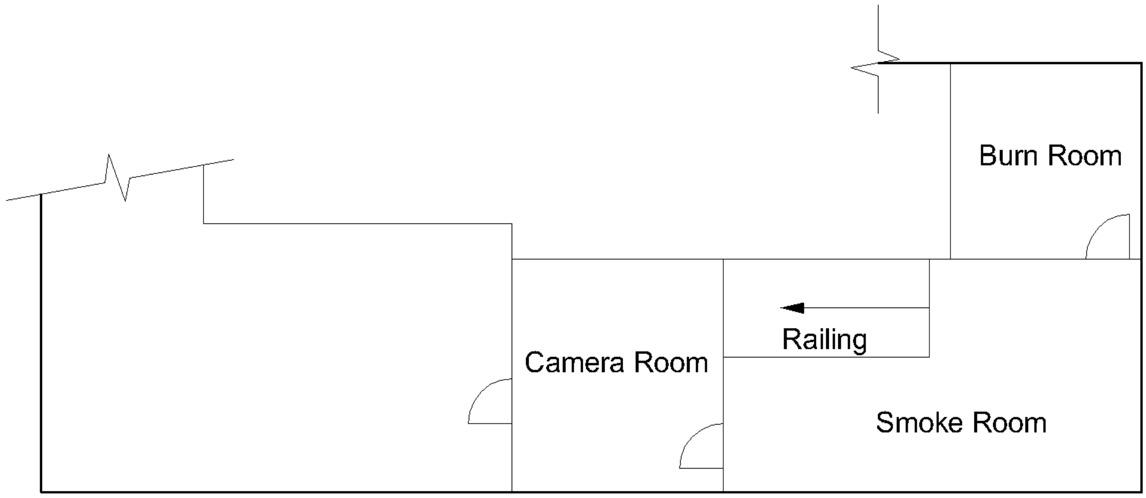

Figure 6: Layout of rooms used for testing various camera technologies at QFES Whyte Island facility

Figure 7: Photos taken during Live Fire Tests at different stages of test

Figure **8** shows the images taken at the start of a test conducted before smoke was introduced into the room. The top left image shows the image recorded with a standard CCTV camera. The top right image shows the image taken with a FLIR thermal LWIR camera, the bottom right image was taken with an IECEx thermal LWIR camera. The bottom left image was taken with a Photonics Science SWIR camera. Note that field of vision for each of the cameras is the same. The widest field is shown with the CCTV camera. A doorway is clearly seen in this image, and it is at or through this doorway that the other cameras are focused. A useful reference point is the railing that can be seen at the centre bottom of the CCTV image, and which can be seen in the other three images.

Figure 8 : Top Left: Standard CCTV Camera, Top Right: FLIR Thermal IR, Bottom Right: IECEx Thermal IR, Bottom Left: Photonics Science SWIR. The images were taken at the start of the test

Smoke was introduced to the room until 90% opacity was reached. For comparison, it is no longer possible for a person to see their hand in front of their face when 30% opacity is reached. Figure 9 shows what can be seen by the various cameras at this point in time.

Figure 9: Top Left: Standard CCTV Camera, Top Right: FLIR Thermal IR, Bottom Right: IECEx Thermal IR, Bottom Left: Photonics Science SWIR, image taken at 90% opacity

As is to be expected, the CCTV image is completely obscured. The thermal LWIR cameras show a clear image due to the increasing contrast in heat being emitted from the various objects in the room. The Photonic Science SWIR image is also good, though the image quality may be slightly degraded.

As the room cools down, the thermal IR images degrade. Figure 10 shows the images taken on another test. Smoke had previously been introduced to the room and ventilation has been applied to the room to remove the smoke. The top images are those taken with the CCTV camera and the bottom images were taken with the FLIR thermal IR camera. The left images were taken just after the smoke was cleared. The right images were taken 20 minutes later.

Figure 10: Top images are taken by a standard CCTV camera, the bottom images by a Thermal LWIR camera, the images on the left side show the room after a smoke test and the contents of the room are still warm, the images on the right show the room after it has cooled down for 20 min and the degradation in image quality of the Thermal IR camera can be seen.

There is a marginal increase in image quality of the CCTV camera as the remnants of the smoke are cleared. The thermal LWIR image, however, decreases significantly in quality. This is due to the room cooling and the temperature difference between the various objects in the room decreasing.

In an underground mine situation, it is not expected that there will be a significant temperature gradient between various objects unless the miners are next to a fire. As such, the thermal IR cameras are not the optimum camera for use on a mine escape vehicle. The SWIR camera images were good across a wide variety of visibility and temperature conditions. A new SWIR camera is in the process of being commissioned at Simtars and further testing will be conducted using this type of camera as the initial results observed are very promising.

CONCLUSIONS

This paper has presented the scope of work that Simtars is currently undertaking into optical and scanning technology for aiding mine escape vehicle navigation. A summary of the initial results from the live fire testing has been presented, with IR camera technology showing very promising results to date. Further testing will be carried out using other technologies including a new un-cooled SWIR camera, LiDAR based scanning and other radio based navigation technologies. Figure 11shows an image of Time of Flight (ToF) based wireless sensor network technology that Simtars is currently evaluating for positioning and navigation technologies.

A series of further tests will be carried in 2016 using the bespoke Smoke and Dust Chamber to identify and refine the appropriate technology. Following on from this an underground mine trial using these technologies will be conducted.

Figure 11: Wireless sensor network based positioning system

Related to this research area, Simtars is currently engaged in developing technology for emergency response applications. This will rely on adopting a resilient wireless communication system that will be initiated following an emergency event in order to collect and transmit vital information to the surface. The technology functionality and performance of the wireless sensor networks is largely understood in underground mining, however, a key requirement of such a system will be the survivability in any explosion or rock fall. Such technology may be of benefit for both aiding the self-escape of mine personnel and also in providing vital information to aid in key decision-making at the surface during an emergency event.

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REFERENCES

Kissell, F N and Litton, C D, 1992. How smoke hinders escape from coal mine fires, *Mining Engineering*, Jan, 79-83.

Sammarco, J J, 2012. An overview of NIOSH mine illumination research: past, present, and future, in *Proceedings SME Annual Meeting 2013,* (Society for Mining, Metallurgy, and Exploration: Denver CO).

Thermal Beacon, 2003. Principals of operation thermal beacon DMR MKII [online]. Available from: < http://www.defence-industries.com/defenceadmin/upload//productspec_pdf/1381665157dmr-v3.pdf > [Accessed: 14 January 2016].

UTC Aerospace Systems, 2016. Why SWIR [online]. Available from: <http://www.sensorsinc.com/technology/why-swir/> [Accessed: 14 January 2016].